Journal of Clinical & Experimental
Cardiology

Kuo CD et al., J Clin Exp Cardiolog 2014, 5:8
DOI: 10.4172/2155-9880.1000331

Research Article Open Access

Left-right Asymmetry of Pulse Harmonics in Non-pregnant Women and Late Pregnant Women

Yi-Ju Su[1], **Wan-An Lu**[2#], **Hsiang-Tai Chao**[3] **and Cheng-Deng Kuo**[1*]

[1]*Laboratory of Biophysics, Department of Medical Research, Taipei Veterans General Hospital, Taipei, Taiwan*

[2]*Institute of Cultural Asset and Reinvention, Fo University, Ilan, Taiwan*

[3]*Department of Obstetrics and Gynecology, Taipei Veterans General Hospital, Taipei, Taiwan*

[#] *Equal contribution with first author*

[*]**Corresponding author:** Cheng-Deng Kuo, Laboratory of Biophysics, Department of Medical Research, Taipei Veterans General Hospital, Taipei 112, Taiwan, Tel: 886 2 28757745; Fax: 886 2 28710773; E-mail: cdkuo23@gmail.com

Rec date: May 12, 2014, **Acc date:** Aug 21, 2014, **Pub date:** Sept 04, 2014

Abstract

Background: The pulses palpated on the left and right radial arteries are said to have diagnostic significances in traditional Chinese medicine. This study investigated whether the pulse waveforms recorded at bilateral index fingers are differentiable by comparing the power spectra of pulse waveform between bilateral pulses and between non-pregnant and late pregnant women.

Methods: Forty seven healthy non-pregnant women and 23 women in the third trimester of pregnancy were included in this study. A train of pulse waveform recorded via a pulse oximeter was acquired and transformed into power spectrum by means of fast Fourier transformation. The power spectra of bilateral pulse waveform were compared with each other in non-pregnant and late pregnant women.

Results: The total power of pulse (TPp) of right pulse and normalized powers of the 5th, 6th, 7th, 8th harmonics (nP5~nP8) of bilateral pulses in late pregnant women were significantly smaller than their counterparts in non-pregnant women, whereas the normalized powers of the 2nd harmonics (nP2) of left and right pulses in late pregnant women were significantly greater than their counterparts in non-pregnant women. The nP4 and nP5 of left pulse were significantly smaller than those of right pulse in the non-pregnant women, but this left-right asymmetry in nP4 and nP5 disappeared in late pregnant women.

Conclusion: Pregnancy can lead to a decrease in the TPp of right pulse, and nP5~nP8 of bilateral pulses, but an increase in nP2 of bilateral pulses. The nP4 and nP5 of left pulse are significantly smaller than those of the right pulse in non-pregnant women, but this left-right asymmetry in nP4 and nP5 disappears during late pregnancy. The changes in bilateral pulse waveform might be associated with the aorto-caval compression during late pregnancy.

Keywords: Pulse; Asymmetry; Energy; Harmonics; Power; Pregnancy

Introduction

Arterial pulse is not only one of the fundamental signs in clinical medicine, but has also been regarded by the physicians as the art of medicine [1]. One of the most commonly used techniques for the diagnosis of diseases in traditional Chinese medicine is the palpation of both radial arteries, the so-called pulse diagnosis. The pulses felt or palpated on the left and right radial arteries are said to have different diagnostic meanings in traditional Chinese medicine.

Many textbooks of traditional Chinese medicine even claim that the palpation of three locations along radial arteries of both hands can provide important information about the organ systems, and can be used in the diagnosis and assessment of physiological conditions and diseases [1-3]. Therefore, it is expected that there must be some changes in the arterial pulse wave in diseased patients and in subjects with altered physiological conditions such as pregnancy.

The necessity of palpating the pulses of bilateral radial arteries to make diagnosis in traditional Chinese medicine might be conceivable because the location of heart in the thoracic cavity is not left-right symmetric, the anatomy of the vessels emanating from the aortic arch is not left-right symmetric, and the distances from the heart to the left and right wrists are not the same. Therefore, the pulse waveform recorded at both radial arteries or index fingers might not be the same. Though the peripheral pulse is still palpated by doctors of traditional Chinese medicine, some techniques are now available for objective, non-invasive assessment of the pulse [4,5]. For instances, peripheral pulse has been used in the assessment of health and disease [6,7] in the assessment of vascular diseases such as occlusive arterial disease [8,9] and can provide information about the cardiovascular system, such as heart rate, pulsatile pressure, and properties of blood vessels, including arterial elasticity, narrowing or occlusion [10-15].

Pulse oximetry has been adopted as an intraoperative and post-operative monitoring standard. For better clinical monitoring of the cardiovascular status of the patients, investigation into the plethysmographic waveform of the pulse oximetry might provide deeper insight into the cardiovascular function of the patients. For instance, the pulse plethysmography has been shown to be useful in the monitoring of vascular sympathetic tone spectral analysis of plethysmographic waveforms has been used to assess the peripheral vascular disease [16-18]. Thus, the pulse waveform can be used to provide a non-invasive surrogate for the intra-arterial waveform, and the pulse oximeter waveform analysis can be used as a measure of the circulatory status.

To unveil the mystery of pulse diagnosis in traditional Chinese medicine a little bit, this study compared the power spectra of the pulse waveforms recorded at bilateral index fingers via pulse oximeter in both non-pregnant and late pregnant women.

Methods

Study Subjects

Forty seven healthy non-pregnant women and 23 women in the third trimester of pregnancy recruited from the community were included in this study. The normal healthy women included in this study were adult women who were not pregnant, not during menstrual period, and before menopause. All late pregnant women had vertex presentation of the fetus with gestational age between 29 and 40 weeks and had no apparent cardiopulmonary distress, obstetric or medical complications of pregnancy.

None of the subjects had major diseases known to affect the pulse, including Raynaud's disease, atrial fibrillation, frequent ventricular ectopic beats, significant limb tremor, deformation of limbs, and hypertension (defined as systolic blood pressure >140 mm Hg and/or diastolic blood pressure >90 mmHg). Nor did they take medicine, drink alcohol or smoke. This study has been approved by the Institute Review Board of Taipei Veterans General Hospital, Taiwan. All procedures, risks, and benefits were explained to the subjects, and informed written consent was obtained from each subject prior to the study.

Measurement Protocol

All measurements were performed at about the same time of the day in the morning (9:00-11:30 AM, after breakfast) to avoid the effects of circadian rhythm on the pulse wave. All subjects were requested not to drink caffeinated beverages for at least 24 h before pulse wave recording. A 10 minutes' rest was routinely requested before this study.

The pulse wave recording was performed with the subject in sitting position to minimize the aorto-caval compression in late pregnant women. The probe of the pulse oximeter was applied to bilateral index fingers in random order, and the tightness of the probes on both fingers was of similar degree. The subjects were requested to relax and breathe normally. The pulse waveforms were recorded for 10 minutes by the bedside plethysmographic monitor (Biochem Vital Sign Monitor, USA) and were transmitted to a personal computer for recording. The sampling frequency for the pulse signals was 500 Hz. If there was any sign or symptom of intolerance to the sitting position such as restlessness, dizziness or pallor, the recording was discontinued.

A total of 2^{15}(=32,768) data points of the pulse waveform from each index finger were obtained for the calculation of power spectrum by fast Fourier transformation (Mathcad 11, Mathsoft Inc., Cambridge, MA, USA). The direct current was excluded before the calculation of power spectra. After fast Fourier transformation, the major peak with maximum intensity located at around the heart rate was identified as the 1st harmonics of the power spectrum. Serial peaks located at multiples of heart rate were identified as the 2^{nd}, 3^{rd}…harmonics of the power spectrum. Beyond the 8th harmonic, the spectral peaks were too small to be identified. Therefore, only eight spectral peaks were included in the statistical analysis in this study.

Let the major frequency at which the i^{th} harmonics occurred be designated as Fi. The area under the curve of the spectral peaks within the range from Fi −0.3 Hz to Fi +0.3 Hz was defined as the power of the i^{th} harmonic (Pi). The area under the wave of the spectral peaks within the whole range from zero Hz to the Nyquist frequency was defined as the total power of pulse (TPp). The power of the i^{th} harmonic divided by the total power (nPi=Pi/TPp) was defined as the normalized power of the n^{th} harmonic.

Statistical Analysis

All data are presented as medians (25%~75%). Mann-Whitney rank sum test (SigmaStat statistical software, SPSS Inc., Chicago, IL, USA) was employed to compare the clinical characteristics, TPp and nPi between late pregnant and non-pregnant women with significance level set at $p < 0.05$. Wilcoxon signed rank test was used to compare the TPp and nPi between left and right pulses in either group of women with significance level set at $p < 0.5/9 \sim 0.0056$, because 1 TPp and 8 nPi were compared. The power of comparison between the 2 groups given specific sample sizes was calculated using G*Power analysis program version 3.1.9.2.

Results

No subjects felt uncomfortable or had any complaint during the period of pulse wave recording. The basic characteristics of the subjects are reported in Table 1. There was no significant difference in the age and body height of the subjects in these two groups. The body weight, body mass index (BMI), heart rate and pulse pressure of the late pregnant women were significantly increased, as compared with the non-pregnant women. No significant differences in systolic, diastolic and mean arterial blood pressures were found between non-pregnant and late pregnant women.

The TPp of right pulse and the normalized powers of the 5^{th}, 6^{th}, 7^{th}, 8^{th} harmonics (nP5~nP8) of bilateral pulses were significantly decreased, while the normalized powers of the 2^{nd} harmonics (nP2) of bilateral pulses were significantly increased in the late pregnant women, as compared with their counterparts in the non-pregnant women (Table 1).

Table 2 shows that the nP4 and nP5 of the left pulse in the non-pregnant women were significantly smaller than their counterparts in the right pulse. However, this left-right asymmetry in pulse harmonics disappeared in the late pregnant women.

Discussion

Effect of pregnancy on pulse wave: Pregnancy is associated with substantial changes in the cardiovascular system of the mother. It has been noted that blood volume, cardiac output and stroke volume begin to change after the first trimester to accommodate the growing fetus [19,20]. Systemic vascular resistance is also known to decrease in response to haemodynamic changes during pregnancy [21-23]. Thus, the increase in pulse pressure in the late pregnant women observed in

Citation: Su YJ, Lu WA, Chao HT, Kuo CD (2014) Left-right Asymmetry of Pulse Harmonics in Non-pregnant Women and Late Pregnant Women. J Clin Exp Cardiolog 5: 331. doi:10.4172/2155-9880.1000331

this study is the normal haemodynamic change in the cardiovascular system during pregnancy.

	Non-pregnant	**Late-pregnant**	**p value**	**Power**
	(n=47)	(n=23)		
Age (year)	29 (25~36)	31 (28~33)	0.511	0.066
Gestational age (week)	NA	34 (32~38)	NA	NA
Body height (cm)	160.0 (158.0~163.0)	160.0 (156.0~163.0)	0.552	0.106
Body weight (Kg)	52.0 (50.0~61.5)	64.0 (61.0~71.5)*	<0.001	0.976
BMI (Kg/m^2)	20.7 (19.1~22.4)	25.7 (23.9~27.7)*	<0.001	0.989
Heart rate (bpm)	75.5 (69.0~84.3)	85.0 (78.3~95.0)*	0.008	0.877
Blood pressure (mmHg)				
Systolic	103.5 (95.5~116.0)	110.0 (91.3~114.0)	0.813	0.068
Diastolic	68.0 (62.8~77.3)	64.0 (51.0~73.5)	0.125	0.611
Mean pressure	78.5 (72.7~90.2)	80.0 (64.8~86.0)	0.315	0.362
Pulse pressure	36.0 (32.0~42.0)	41.5 (39.0~49.3)*	0.007	0.761
Right hand pulse harmonics				
TPp (au^2)	20150 (17480~23220)	19140 (14850~20580)*	0.047	0.463
nP1	65.9 (60.8~71.6)	65.0 (57.6~72.9)	0.671	0.086
nP2	9.6 (9.0~12.1)	17.2 (13.6~23.9)*	<0.001	~1.000
nP3	3.1 (2.0~4.0)	2.6 (2.1~3.1)	0.133	0.568
nP4	0.59 (0.35~0.82)	0.70 (0.52~0.79)	0.416	0.063
nP5	0.33 (0.21~0.42)	0.17 (0.11~0.28)*	<0.001	0.936
nP6	0.09 (0.06~0.18)	0.02 (0.02~0.06)*	<0.001	0.806
nP7	0.02 (0.01~0.04)	0.01 (0.01~0.02)*	<0.001	0.605
nP8	0.008 (0.005~0.013)	0.004 (0.002~0.010)*	0.007	0.447
Left hand pulse harmonics				
TPp (au^2)	23180 (19420~25340)	20640 (16440~23810)	0.074	0.491
nP1	65.1 (58.7~72.3)	63.2 (57.6~70.7)	0.617	0.065
nP2	9.5 (8.3~11.8)	19.5 (11.1~21.2)*	<0.001	~1.000
nP3	2.5 (2.0~3.5)	2.3 (1.8~2.9)	0.154	0.589
nP4	0.46 (0.30~0.68)	0.61 (0.40~0.73)	0.245	0.066
nP5	0.24 (0.19~0.33)	0.16 (0.12~0.22)*	<0.001	0.94
nP6	0.08 (0.05~0.13)	0.03 (0.02~0.05)*	<0.001	0.978
nP7	0.02 (0.01~0.03)	0.01 (0.01~0.01)*	<0.001	0.869
nP8	0.007 (0.006~0.011)	0.003 (0.002~0.010)*	<0.001	0.916

Table 1: The clinical characteristics of the non-pregnant and late pregnant women. All data are presented as medians (25%~75%). *$p < 0.05$ vs non-pregnant women. NA : Not applicable; bpm: Beat per minute; au: Arbitrary unit

	Right hand	Left hand	p value	Power
Non-pregnant women (n=47)				
TPp (au^2)	20150 (17480~23220)	23180 (19420~25340)	0.046	0.999
nP1	65.9 (60.8~71.6)	65.1 (58.7~72.3)	0.152	0.568
nP2	9.6 (9.0~12.1)	9.5 (8.3~11.8)	0.515	0.508
nP3	3.1 (2.0~4.0)	2.5 (2.0~3.5)	0.059	0.818
nP4	0.59 (0.35~0.82)	0.46 (0.30~0.68)*	<0.001	0.952
nP5	0.33 (0.21~0.42)	0.24 (0.19~0.33)*	<0.001	0.999
nP6	0.09 (0.06~0.18)	0.08 (0.05~0.13)	0.008	0.955
nP7	0.02 (0.01~0.04)	0.02 (0.01~0.03)	0.109	0.781
nP8	0.008 (0.005~0.013)	0.007 (0.006~0.011)	0.593	0.491
Late pregnant women (n=23)				
TPp (au^2)	19140 (14850~20580)	20640 (16440~23810)	0.37	0.943
nP1	65.0 (57.6~72.9)	63.2 (57.6~70.7)	0.403	0.43
nP2	17.2 (13.6~23.9)	19.5 (11.1~21.2)	0.796	0.314
nP3	2.6 (2.1~3.1)	2.3 (1.8~2.9)	0.039	0.94
nP4	0.70 (0.52~0.79)	0.61 (0.40~0.73)	0.034	0.998
nP5	0.17 (0.11~0.28)	0.16 (0.12~0.22)	0.212	0.812
nP6	0.02 (0.02~0.06)	0.03 (0.02~0.05)	0.241	0.772
nP7	0.01 (0.01~0.02)	0.01 (0.01~0.01)	0.025	0.896
nP8	0.004 (0.002~0.010)	0.003 (0.002~0.010)	0.194	0.963

Table 2: Comparisons of the total power of pulse and the normalized pulse harmonics in the power spectra between right and left pulses in the non-pregnant and late pregnant women. *p<0.0056 vs right pulse, au: Arbitrary unit

We found in this study that the TPp of right pulse, and nP5~nP8 of bilateral pulses in the late pregnant women were all significantly smaller than their counterparts in the non-pregnant women, whereas the nP2 of bilateral pulses in the late pregnant women were significantly greater than their counterparts in the non-pregnant women, in accordance with a previous study [24]. The decrease in TPp of right pulse, and nP5~nP8 of bilateral pulses in the late pregnant women might be caused by the aorto-caval compression due to enlarged gravid uterus in late pregnancy. The mechanism of increased nP2 of bilateral pulses in the late pregnant women is not well understood at present. The change in pulse waveform due to decreased systemic vascular resistance during pregnancy [21-23] might be one of the mechanisms of this phenomenon.

Left-right asymmetry in pulse wave: Efficient pulse wave transmission depends on the mechanical and geometric properties of the conduit vessels and on the status of the vasculature. In this study, we found that the nP4 and nP5 of left pulse was significantly smaller than those of right pulse in the non-pregnant women. This left-right asymmetry in TPp might be caused by the asymmetric geometry of the heart and associated vasculature in the thoracic cavity, such as the deviation of the heart to the left thorax, the asymmetric geometry of the arteries emanating from the aortic arch, and the unequal distances from the heart to the left and right index fingers. However, this left-right asymmetry in nP4 and nP5 diminishes during late pregnancy. It seems that gestation has added a workload to the pregnant women so as to eliminate the left-right asymmetry in the pulse waveform by changing the anatomical structure of the cardiovascular system.

One of the most commonly used techniques for the diagnosis of diseases in traditional Chinese medicine is the palpation and feeling of both radial arteries. The pulses felt on the left and right radial arteries are claimed to have different diagnostic significances in traditional Chinese medicine. This assertion of the traditional Chinese medicine is not easy to understand, but might be appreciated in view of the facts that the distribution and ramification of blood vessels within the body is not exactly axially symmetric. Our study suggested that the pulses recorded at bilateral index fingers in non-pregnant and late pregnant women are differentiable through the use of power spectral analysis. The left-right asymmetry in pulse waveform in non-pregnant women and the disappearance of this left-right asymmetry in pulse waveform during late pregnancy seem to conform to the concept of the traditional Chinese medicine that the palpation of both right and left radial arteries is necessary for the better understanding of various kinds of diseases and pregnancy. This finding might have some clinical applications in the future.

Conclusion

Pregnancy can decrease the TPp of right pulse, and nP5~nP8 of bilateral pulse, but increase the nP2 of bilateral pulses. The left-right asymmetry in nP4 and nP5 in non-pregnant women disappear during late pregnancy. These changes in pulse harmonics of bilateral pulses during pregnancy might be associated with the aorto-caval compression during late pregnancy. Pulse wave analysis might be useful in the clinical diagnosis, monitoring and prognosis evaluation of pregnancy and associated diseases in the future.

Acknowledgment

This study was supported by grants V97C1-110 and V98C1-008 from the Taipei Veterans General Hospital, Taipei, Taiwan, and a grant NSC100-2314-B-075-026 from the National Science Council, Taipei, Taiwan.

References

1. Lo YK (1987) Gynaecology of Traditional Chinese Medicine (2nd edn.) Shanghai Science and Technology Publisher, Shanghai.
2. Shen ZY (1995) Textbook of Traditional Chinese Medicine. Shanghai Medical University Publisher, Shanghai.
3. Xiang ZX (1999) The Analysis of Pulse Pattern and Disease Treatment of Traditional Chinese Medicine. Traditional Chinese Medicine Publisher, Beijing.
4. AbuRahma AF, Diethrich EB (1988) Current Non-Invasive Vascular Diagnosis. PSG Publishing Company, Philadelphiam MA, USA.
5. Barnes RW (1991) Noninvasive diagnostic assessment of peripheral vascular disease. Circulation 83: I20-27.
6. Nichols WM, O'Rourke MF (1990) McDonald's Blood Flow in Arteries (3rd edn.) Edward Arnold, London.
7. O'Rourke MF, Kelly RP, Avolio AP (1992) The Arterial Pulse. Lea & Febiger, London.
8. Kester RC, Leveson SH (1981) A Practice of Vascular Surgery. Pitman Books Ltd, London.
9. Moore WS (1991) Vascular Surgery. A Comprehensive Review. WB Saunders, Philadelphia, USA.
10. Kawarada A, Shimazu H, Yamakoshi K, Kamiya A (1986) Noninvasive automatic measurement of arterial elasticity in human fingers and rabbit forelegs using photoelectric plethysmography. Med Biol Eng Comput 24: 591-596.
11. Asmar R, Benetos A, Topouchian J, Laurent P, Pannier B, et al. (1995) Assessment of arterial distensibility by automatic pulse wave velocity measurement: validation and clinical application studies. Hypertension 26: 485-490.
12. Wilkinson IB, Cockcroft JR, Webb DJ (1998) Pulse wave analysis and arterial stiffness. J Cardiovasc Pharmacol 32 Suppl 3: S33-37.
13. Allen J, Murray A (1999) Modelling the relationship between peripheral blood pressure and blood volume pulses using linear and neural network system identification techniques. Physiol Meas 20: 287-301.
14. Bortolotto LA, Blacher J, Kondo T, Takazawa K, Safar ME (2000) Assessment of vascular aging and atherosclerosis in hypertensive subjects: second derivative of photoplethysmogram versus pulse wave velocity. Am J Hypertens 13: 165-171.
15. Wilkinson IB, Hall IR, MacCallum H, Mackenzie IS, McEniery CM, et al. (2002) Pulse-wave analysis: clinical evaluation of a non-invasive, widely applicable method for assessing endothelial function. Arterioscler Thromb Vasc Biol 22: 147-152.
16. Challoner AV, Ramsay CA (1974) A photoelectric plethysmograph for the measurement of cutaneous blood flow. Phys Med Biol 19: 317-328.
17. Jonson B, Dahn I, Nilsén R (1970) A plethysmographic method for determination of flow and volume pulsations in a limb. J Appl Physiol 28: 333-336.
18. Bennett L, Fischer AA (1985) Spectrum analysis of large toe plethysmographic waveshape. Arch Phys Med Rehabil 66: 280-285.
19. Elkayam U, Gleicher N (1990) Hemodynamics and cardiac function during normal pregnancy and the puerperium. In: Elkayam U, Gleicher N, eds. Cardiac Problems in Pregnancy: Diagnosis and Management of Maternal and Fetal Disease. New York: Alan R. Liss: 5-24.
20. Oakley CM (1990) Cardiovascular disease in pregnancy. Can J Cardiol 6 Suppl B: 3B-9B.
21. Bryant EE, Douglas BH, Ashburn AD (1973) Circulatory changes following prolactin administration. Am J Obstet Gynecol 115: 53-57.
22. Gerber JG, Payne NA, Murphy RC, Nies AS (1981) Prostacyclin produced by the pregnant uterus in the dog may act as a circulating vasodepressor substance. J Clin Invest 67: 632-636.
23. Metcalfe J, Ueland K (1974) Maternal cardiovascular adjustments to pregnancy. Prog Cardiovasc Dis 16: 363-374.
24. Su YJ, Lu WA, Chen GY, Liu M, Chao HT, et al. (2011) Power spectral analysis of plethysmographic pulse waveform in pregnant women. J Clin Monit Comput 25: 183-191.